DEVELOPMENT OF AN ENHANCED THERMAL BARRIER FOR RSRM NOZZLE JOINTS

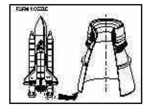
Paul H. Bauer
Thiokol Corporation
Brigham City, Utah

Development of an Enhanced Thermal Barrier for RSRM Nozzle Joints

P. H. Bauer

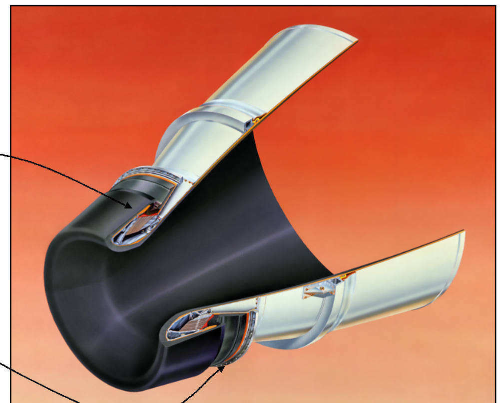
NASA Seal/Secondary Air System Workshop
25 October 2000

RSRM Nozzle



- **Reusable Solid Rocket Motor Joints**
  - * Evaluation
  - ** Qualification

Joint 1 *
Joint 2 **
Joint 3
Joint 4
Joint 5 *
Joint 6 **

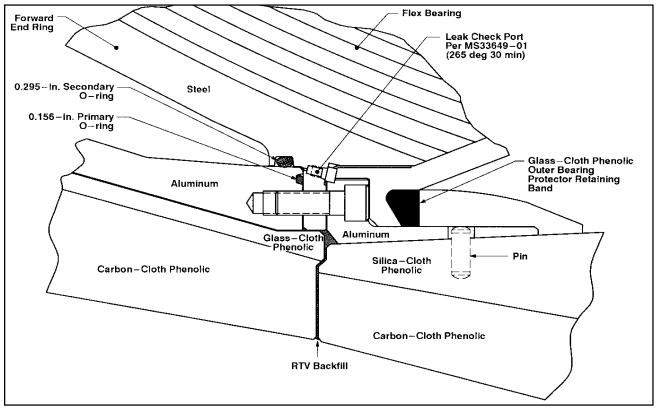


RSRM Nozzle is composed of 6 sections and has 6 sealed joints.

1) Exit cone joint
2) Nose cap to cowl
3) Nose cap to throat
4) Throat to exit cone
5) Bearing to fixed housing
6) Fixed housing to case

RSRM Nozzle Joint 2

- **Joint 2 current design with RTV backfill**



Current joint design uses an RTV backfill material as a thermal barrier and also is meant to function as a redundant seal. In joint 2 it does not function as designed. Joint motion fractures the backfill on most flights and allows pressurization of the o ring seals. In some cases, distinct gas paths may form and can heat-affect paint or even metal nozzle components.

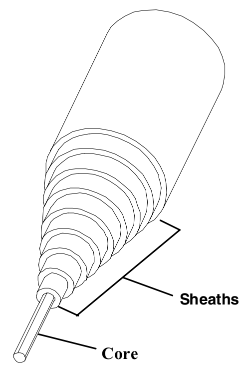
Design Requirements

- Cool propellant gases.
- Filter slag and particulate.
- Conform to various joint assembly conditions as well as dynamic flight motion.
- Maintain positive margins of safety for all affected components.
- Provide barrier redundancy to ensure fault-tolerance.

A re-design effort is underway by Thiokol to eliminate this risk. The redundant seal capability of the current thermal barrier/backfill material will be eliminated. New design will allow by design the pressurization of the o-rings, but ensure that the gasses are benign.

Albany International Techniweave

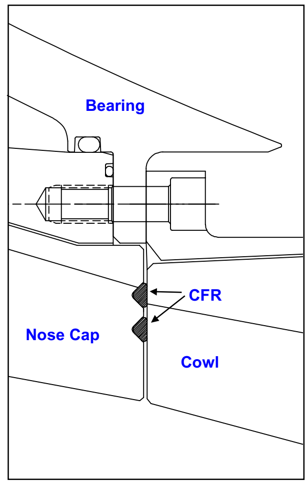
General Details	Rope Diameter	0.260 inches
	Fiber Material	Thornel T-300
	Fiber Diameter	2.76 x 10-4 inches
Core Details	Fiber Count	12 K
Sheath Details	Number of Sheaths	10
	Number of Carriers per Sheath	8 (sheath 1-5) 12 (sheath 6,7) 16 (sheath 8-10)
	Fiber Count per Carrier	1K (sheath 1-3) 3K (sheath 4-10)
	Braid Angle	0º (Core) 17º (sheath 1) 45º (sheaths 2-10)



Replacement material developed and produced by Albany International Techniweave proved to be highly thermally resistant, permeable and easy to handle.

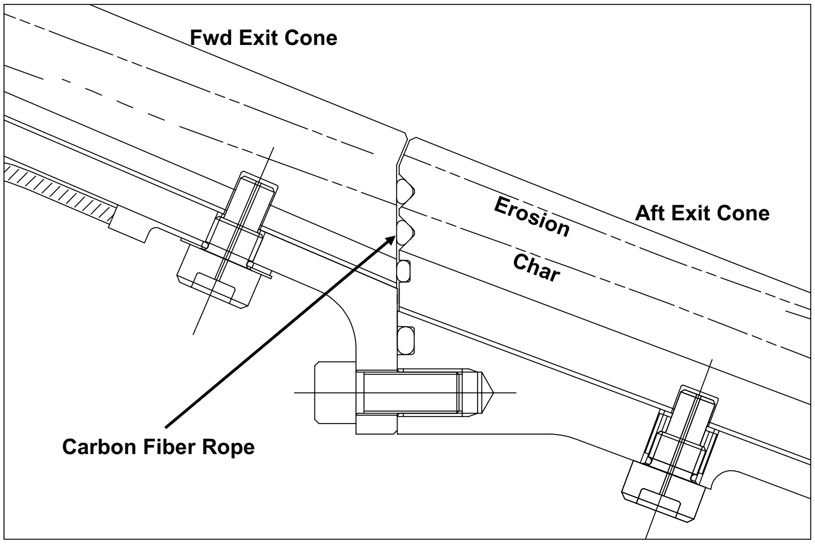
Joint 2 CFR Design

- Fault tolerant.
- Redundant 2-CFR design.
- Accommodates worst case joint tolerances.
- Straightforward to manufacture.
- Trouble-free assembly.



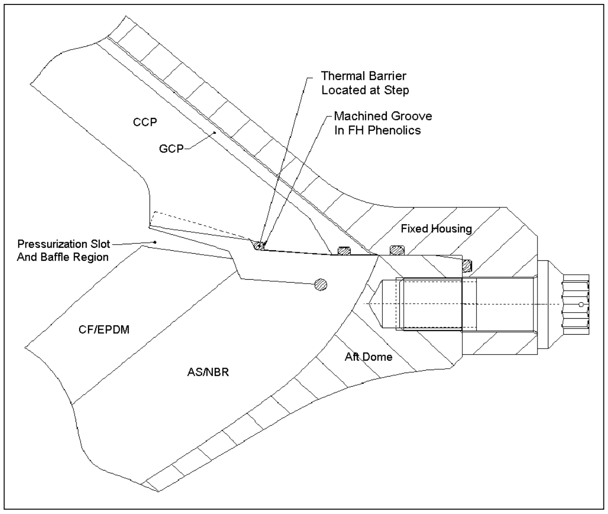
New design is fault tolerant, two barrier design. Each thermal barrier has the capability to cool and filter propellant gasses. Two barriers provides additional factor of safety. Design also accounted for manufacturing and assembly concerns. New barrier design will be much easier and cheaper to build.

Joint 1 CFR Design



Joint 1 is also being considered for redesign. Current concept is similar in most respects to joint 2.

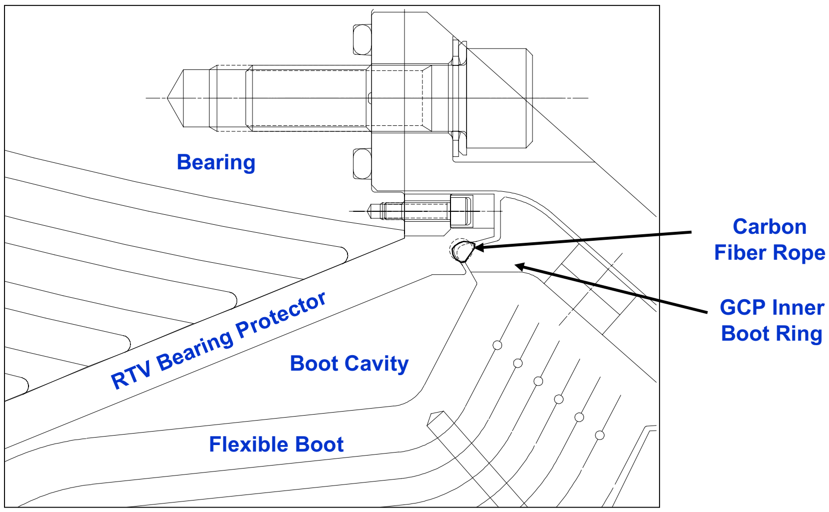
Joint 6 CFR Design



- Fault tolerant
- Accommodates worst-case joint tolerances
- Straightforward to manufacture
- Trouble-free assembly

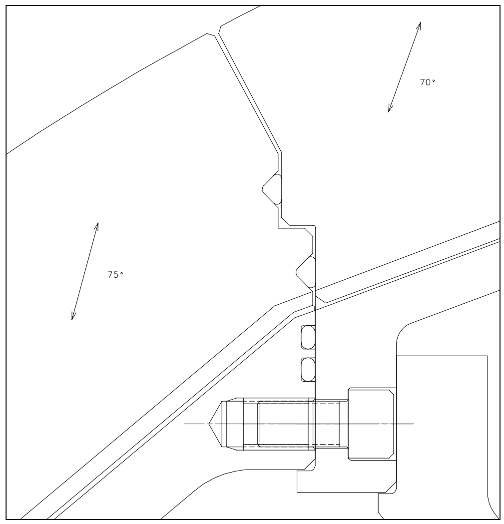
Joint 6 (or nozzle-to-case joint) is also being evaluated for flight. CFR has been located between NBR and CCP phenolic as a backup to the J-leg seal.

Joint 5 CFR Design



Joint 5 concept incorporates a single CFR barrier separating the boot cavity from the primary o-ring. Since boot cavity temperatures are already quite low, a single CFR barrier is being considered.

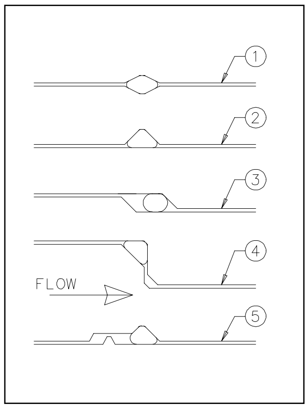
Joint 3 Preliminary Design Concept

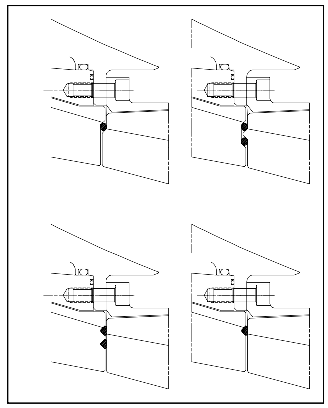


Joints 3 and 4 are being considered for redesign but are behind joints 1, 2, 5, and 6 as far as development.

Design Concepts

- **General design concepts and final four design candidates for joint 2**

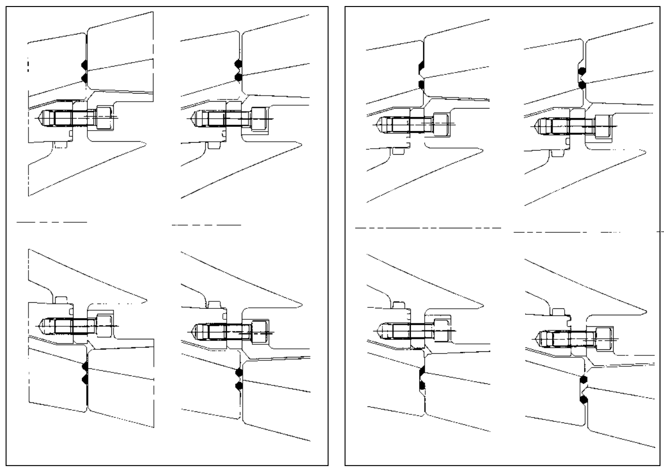




Initial design concepts use a variety gland shapes, some better than others for accommodating tolerance stackup, joint dynamics, manufacturing and installation. The four designs on the left were evaluated for thermal performance.

Tolerance Study

- **Tolerance extremes for face and dogleg gland designs**



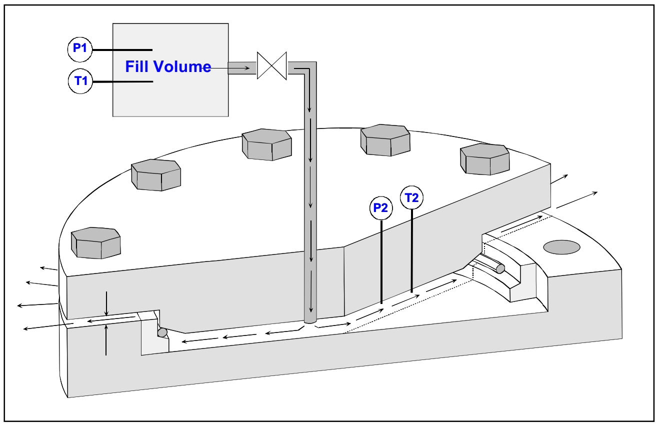
Tolerance study determines the final dimensions of the glands.

Test Program

- Tolerance Stackup Analysis
- JES 1 – Face preferred over dogleg.
- JES 2 – Double-CFR preferred over single.
- JES 3 – Confirm face preference.
- JES 4 – Confirm double-CFR preference.
- JES 5 – Confirm JES 1 results and demonstrate no-rope results.
- JES 6 – Test additional fill volume. (not fired yet)
- Cold Flow Testing
- MNASA-11 – Single-CFR dogleg.
- MNASA-12 – Double-CFR face.
- MNASA-13 – Single-CFR face (not fired yet).
- Circumferential Flow
- Full-scale Assemblies

Outline of test program.

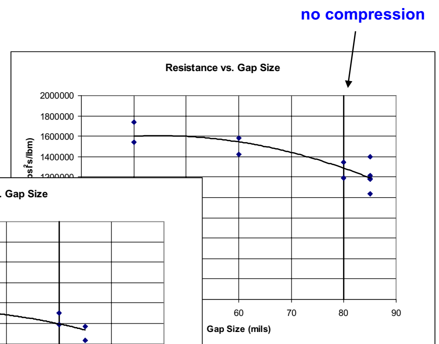
Cold Flow Fixture

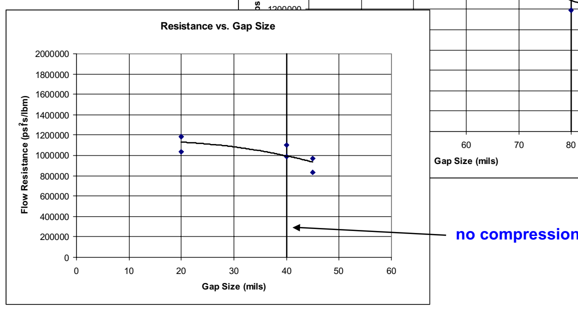


Initial pressure tests show little difference between selected designs.

Preliminary Cold Flow Data

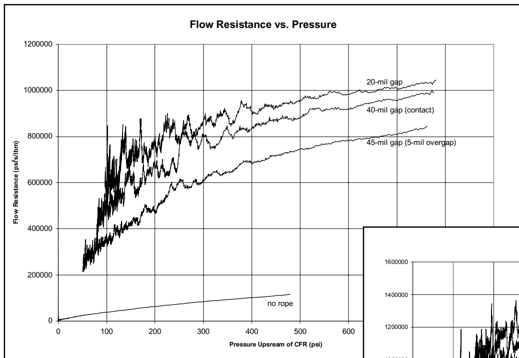
- **Seating**
  - Cold-flow air to ambient pressure.
  - Vary gap and initial pressure.
  - Calculate flow resistance from pressure delta.

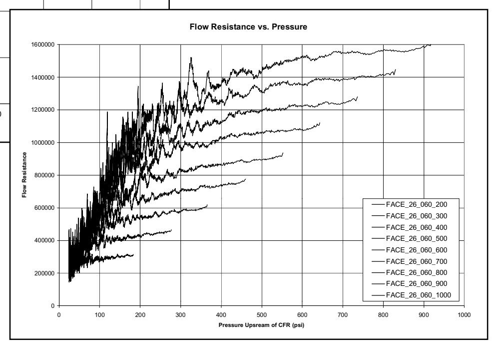




Data shows good flow resistance for a variety of tolerance conditions. Testing covered extreme tolerance conditions where the barrier was no longer in compression. This gave us confidence that the CFR would perform in the dynamic (gap-opening) joint conditions.

Preliminary Cold Flow Data



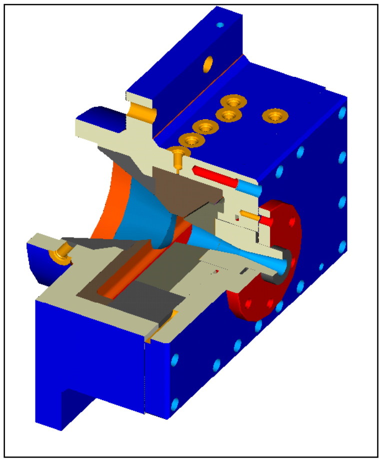


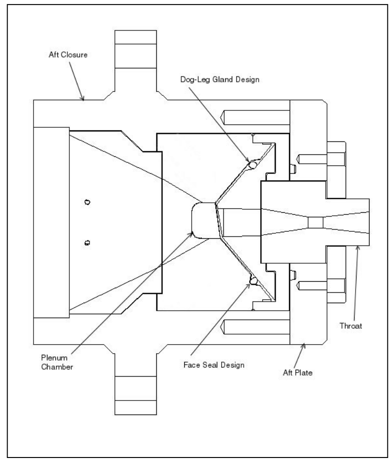
- **Flow resistance increases with increasing pressure differential.**
- **Flow resistance drops with opening gap.**

Flow resistance is not constant with initial pressure. This gave us more evidence that the barrier does react to the pressurization event and should equally distribute the flow circumferentially.

Sub-scale Nozzle JES Testing

- Cutaway view of plenum and test section.

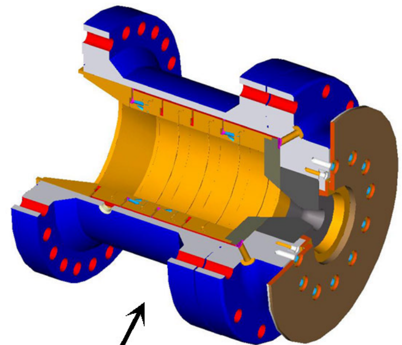


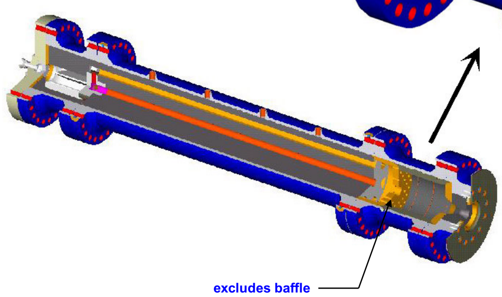


First hot fire test of the CFR in a Joint 2 environment. This motor tests a 5 inch section of CFR and is instrumented to record pressures and temperatures upstream and down stream of one or two CFR barriers.

24-inch Hybrid Motor Configuration

- **Assembly**
  - Motor will consist of a multi-port HTPB Escorez formulated grain with 18% aluminum.
  - Aft section of motor will contain 4 test sections with radial dimensions identical to RSRM Joint 2.

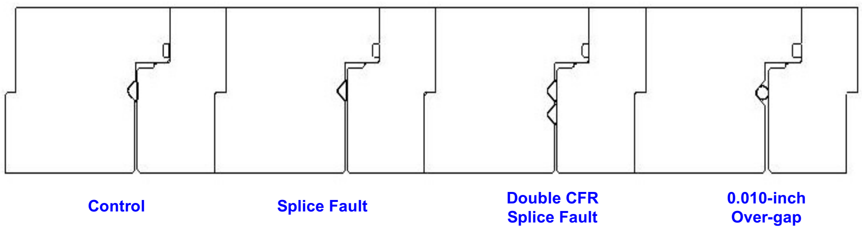




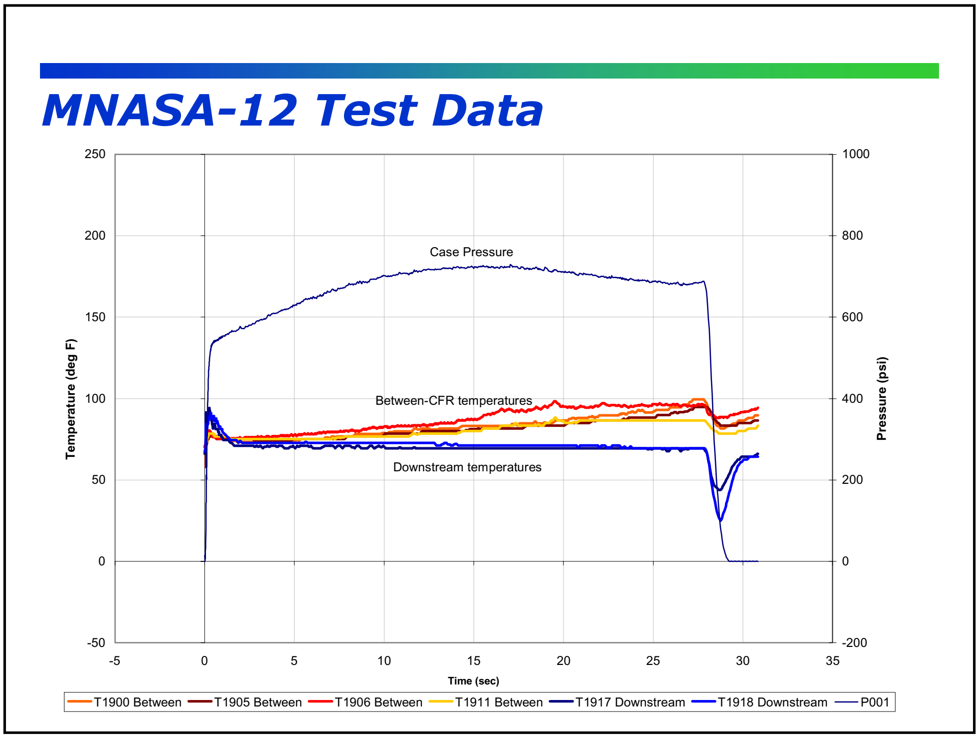
Larger sub-scale motor was recently fired to evaluate the fault-tolerance of the CFR thermal barrier. Results were encouraging, but did bring into question the hot durability of the CFR. High tensile strength material is being evaluated.

Test Sections

- **Test Sections Description**
  - Control – Nominal gap, no flaw.
  - Single CFR– Single Flaw, CFR cut through with 0.050-inch gap.
  - Double CFR – Two Flaws, Clocked 180°
  - Overgap Test – Zero CFR compression, 0.010-inch blow-by path.

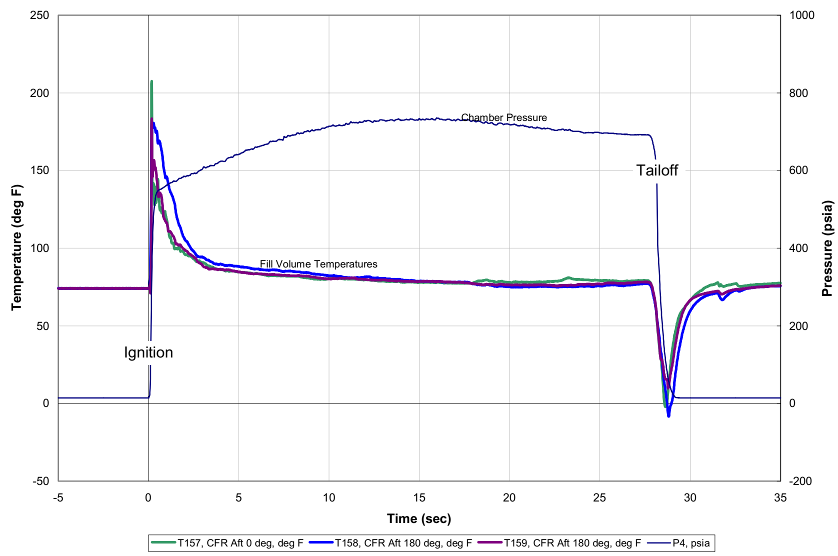


Details of the fault-tolerance test sections. Temperature profiles behind all four barriers were acceptable and no heat affects on any o-rings were noted. All CFR test sections had unexpected broken fibers, but did not affect the performance of the barriers.

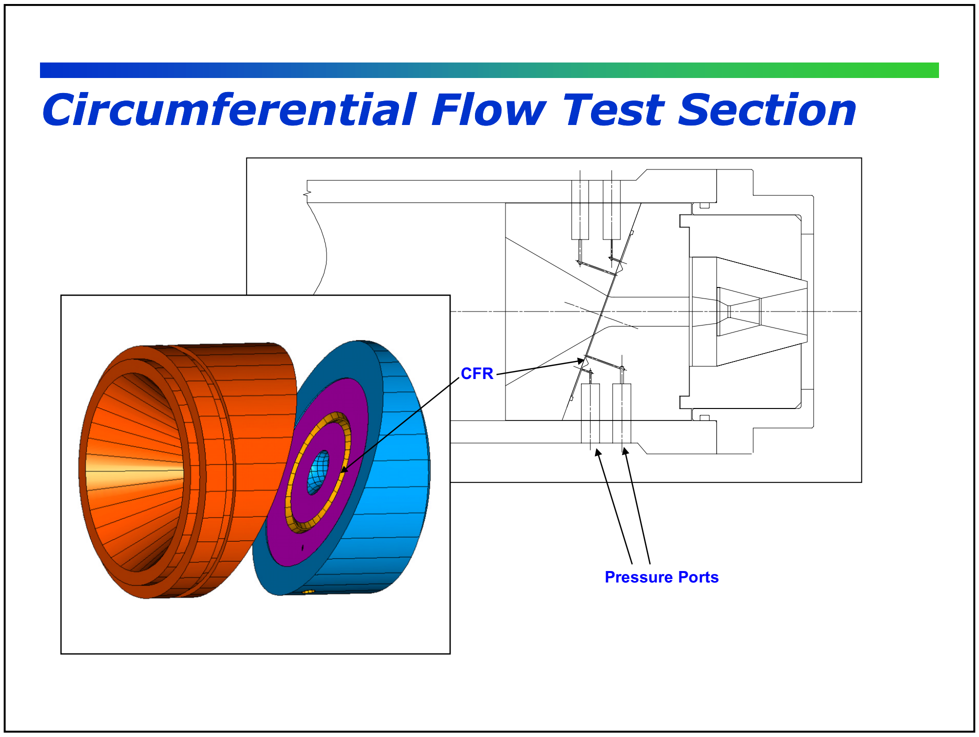


Several subscale RSRM motors were fired with nominal CFR barriers in place. This is test data from one of those motors. Note that the greatest temperature deltas are caused by gas compression and expansion. Heat passed from the combustion process to the thermocouples downstream of the second barrier is not measurable.

MNASA-11 Test Data



Single-barrier test on a subscale MNASA motor shows similar results.



Circumferential flow is a concern in vented system. This test creates circumferential flow in a non-vectored motor with use of a canted test section. Designed to produce a 4-5 psi differential across several inches of CFR, the test is conservative. Actual expected differential pressure is 4-5 psi across 12 feet of CFR. Differential pressure and temperature was recorded both upstream and downstream of the CFR.

Differential Pressure Instrumentation

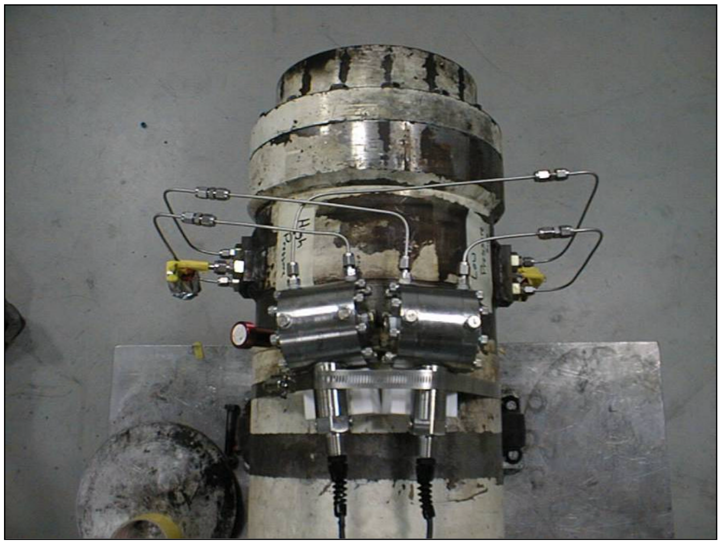
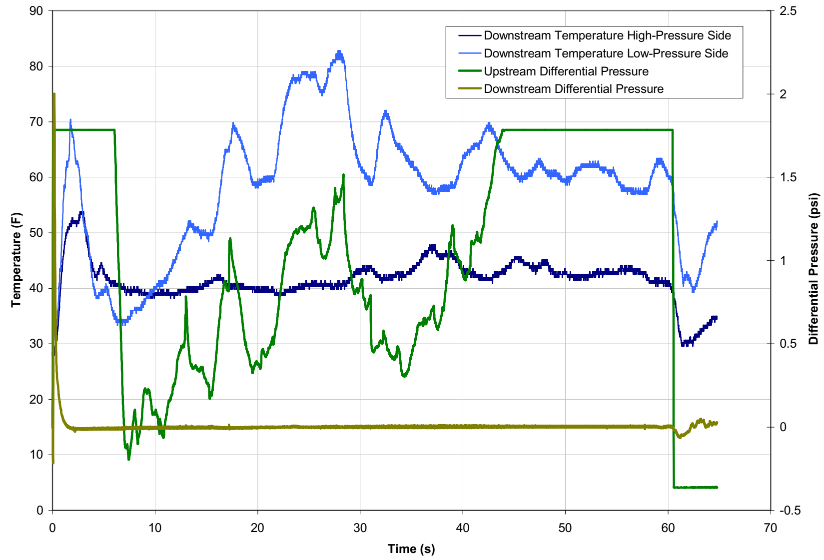


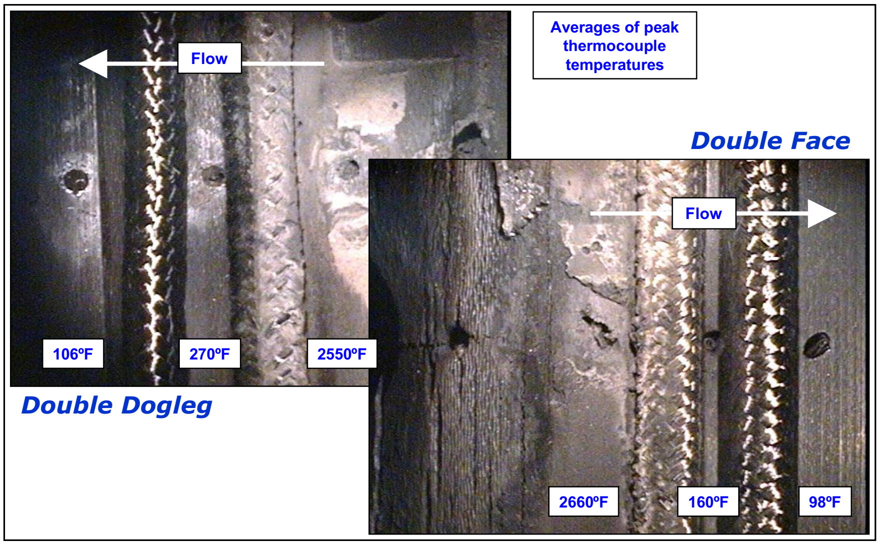
Photo of the actual test setup. Differential pressure gages are external.

Downstream Temperatures



Data shows excellent downstream temperatures. Differential pressure downstream of the barrier is not measurable.

Performance

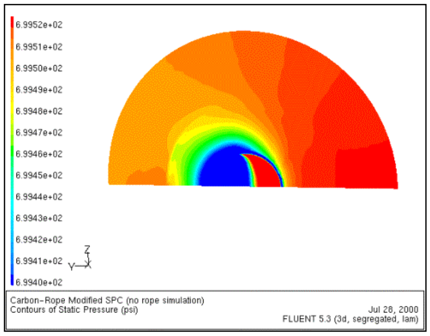


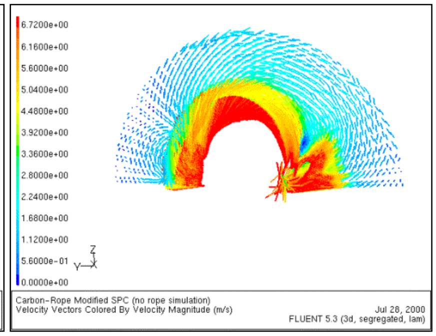
Typical post fire photos and peak temperatures. Note the large temperature change across the first barrier.

Thermal Analysis

SPC - Canted Test Section

No-CFR Pressure and Velocity Distributions





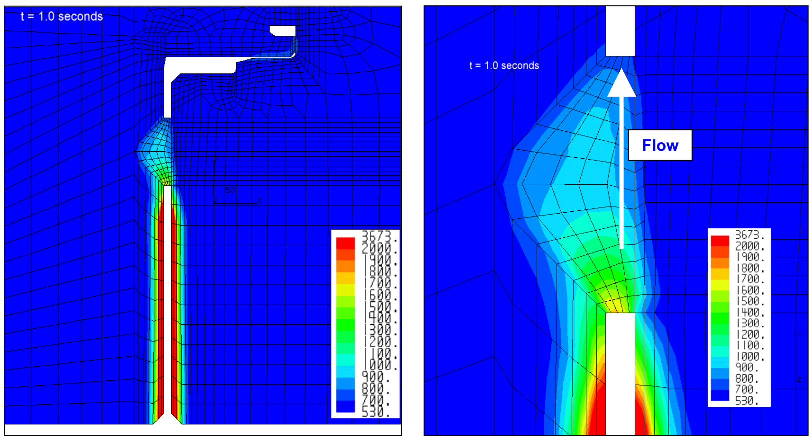
- **Gap alone (no CFR) creates significant resistance to circumferential flow.**
- **Adding CFR flow resistance results in uniform pressure distribution downstream of CFR.**

Circumferential Flow was modeled without CFR.

Thermal Analysis

- **No Circumferential Flow**

Temperature Contours at 1.0 Seconds

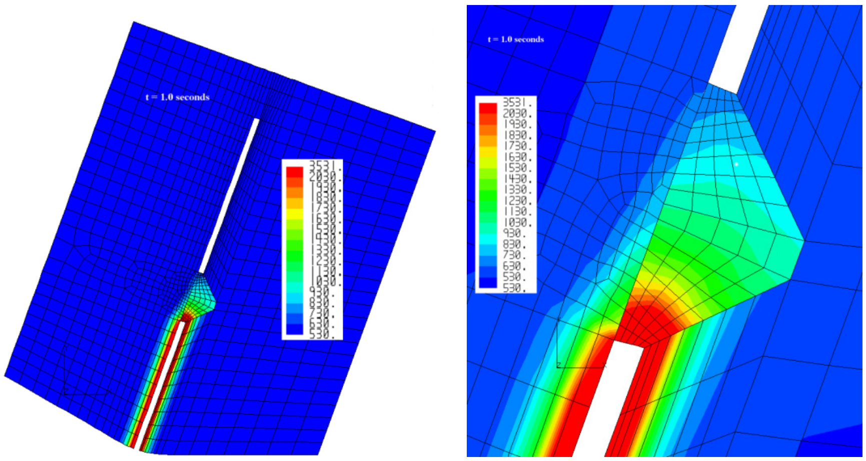


Predicted thermal performance of CFR without circumferential flow. Model is still under development but does match measured results well.

Thermal Analysis

- **Circumferential Flow**

Temperature Contours at 1.0 Seconds



Predictions with circumferential flow show a slight increase in temperature upstream of CFR, but no significant change to the downstream environment.

Summary

- Tolerance study and cold-flow tests provided good basis for project funding.
- All hot-fire tests demonstrated excellent capability. Provides incentive to evaluate all nozzle joints.
- Full-scale testing to be conducted in April 2001.
- More full-scale tests planned.
- Flight implementation for joints 2 and 6 may happen as soon as 2002.
- First flight would then be in fall of 2003.